

Uni-Element Injector Testing

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In order to develop improved injectors for liquid rocket engines, a low-cost, time-effective method for evaluating injector characteristics is needed. A new methodology and test facility are being developed for this purpose at MSFC.

Historically, large subscale hardware at the 40,000-lb thrust level has been used for this purpose. This test hardware is approximately 5 to 15 percent of typical full-scale hardware for launch vehicle applications. Because of the expense and limited data quality of this test approach, injector development programs using it are typically limited to evaluating a small number of injector designs. These designs are usually similar to injectors with an established performance data base.

An alternative method for characterizing injectors is to use a small combustion chamber with windows to conduct extensive evaluation of a single or a small number of injection elements. Quantitative, as well as qualitative, data can be obtained using a combination of advanced optical diagnostic methods and conventional methods. A facility has been established at MSFC for this type of advanced injector development.

The combustion chamber currently being used, known as the uni-element injector test article, is on loan from Aerojet TechSystems. The combustion chamber, which has a 3.42-in inner diameter, is designed to accommodate windows with a viewing diameter of 1.125 in. Three sets of windows provide optical access to the combustion chamber at axial distances of $x=0.5$, 2.25, and 4.0 in from the injector face. At each axial location, windows are at four circumferential positions: 0, 150, 180, and 270 degrees. This configuration allows for a variety of optical techniques that require the light source and receiving optics to be oriented at different angles.

The uni-element hardware was used to examine an oxidizer-rich swirl injection element. The injection element was

provided by the Pennsylvania State University's Propulsion Engineering Research Center (PERC), and it is identical to elements that have been tested at PERC. A cross-sectional diagram of this element is shown in figure 8. The central oxidizer post has an inner diameter of 0.135 in and an outer diameter of 0.165 in. Angular momentum, or "swirl," is imparted to the oxidizer flow as it passes through the slotted openings in the swirl nut at the head end of the injector. The fuel annulus which surrounds the oxidizer post has an outer diameter of 0.280 in.

Liquid oxygen (lox) and gaseous hydrogen (GH_2) were used as the propellants. The lox mass flow rate was fixed at 0.25 lb_m/sec or 0.40 lb_m/sec . The GH_2 mass flow rate was varied to provide mixture ratios (O/F) over the range of 50 to 175. Gaseous nitrogen (GN_2) was injected through the annular injector circuits (both fuel and oxidizer). Additional GN_2 was used in the film coolant circuit at the injector periphery. The GN_2 flowing into the chamber contributed significantly to the total chamber pressure. The mass flow rate of GN_2 was adjusted to set the steady-state chamber pressure at approximately 400 or 800 psia.

Several combustion diagnostic techniques are being applied or are being developed for application to this problem. For example, ultraviolet (UV) images have been taken with an intensified charge coupled device (CCD) camera and a UV filter. Figure 9 shows a series of these individual images taken at a gate speed of 3 μsec . These images were taken at the first window position ($x=0.5$ in), and the direction of flow is from left to right. White pixels indicate regions of high flame intensity. The instantaneous flame structure in these images is quite complex, and significant variation can be seen from frame to frame. The final frame in this sequence is an average of 35 individual images. This average image shows a spray cone with remarkable symmetry, with the region of highest flame intensity located very close to the injector face (<0.5 in).

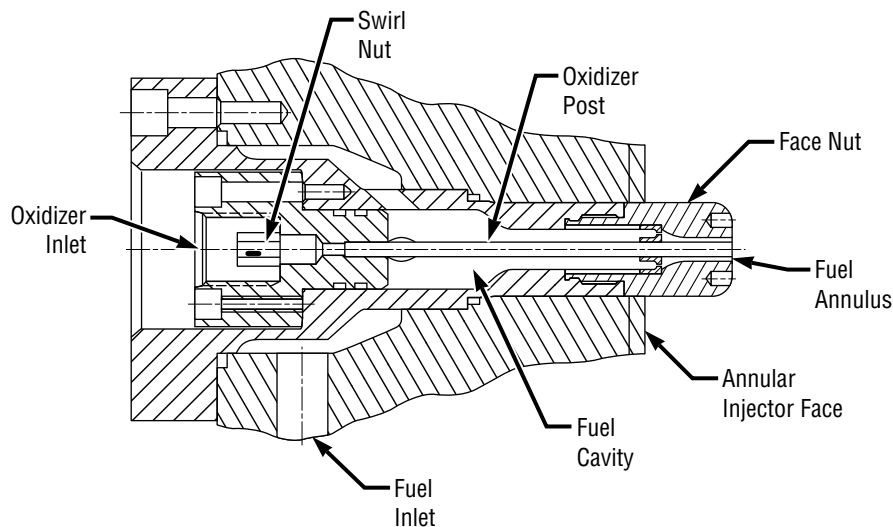


FIGURE 8.—Oxidizer-rich swirl injection element.

Other diagnostic techniques under development include the phase doppler particle analyzer (PDPA) system and Raman spectroscopy. PDPA is an established method for measuring the important characteristics of a liquid spray, in particular droplet size and velocity distributions. Refinement of this technique for rocket engine injection elements is underway at PERC, and collaboration between PERC and MSFC will continue in this area. Recent experimental studies indicate that Raman spectroscopy is a promising technique for gathering local data on major species and temperature with reasonable levels of accuracy. MSFC's approach is to apply a spontaneous Raman scattering technique developed at ambient pressure to pressures of interest for rocket engine applications ($>1,000$ psia). This previous work demonstrated a temporal resolution of 20 ns and

a spatial resolution of 0.4 mm. Comparable levels of resolution are expected at MSFC.

A new approach for assessing the performance of liquid rocket engine injection element designs at MSFC has been established. The test facility and test hardware are operational, and a range of combustion diagnostic techniques to characterize important physical processes are being developed.

Hutt, J.J.; and Cramer J.M.: "Advanced Rocket Injector Development at the Marshall Space Flight Center." AIAA 96-4266, 1996 AIAA Space Programs and Technologies Conference, Huntsville, AL, September 24–26, 1996.

Sponsor: Office of Space Access and Technology; Space Transportation Division

University/Industry Involvement: Aerojet Tech Systems; University of Alabama in Huntsville—Propulsion Research Center; Pennsylvania State University—Propulsion Engineering Research Center

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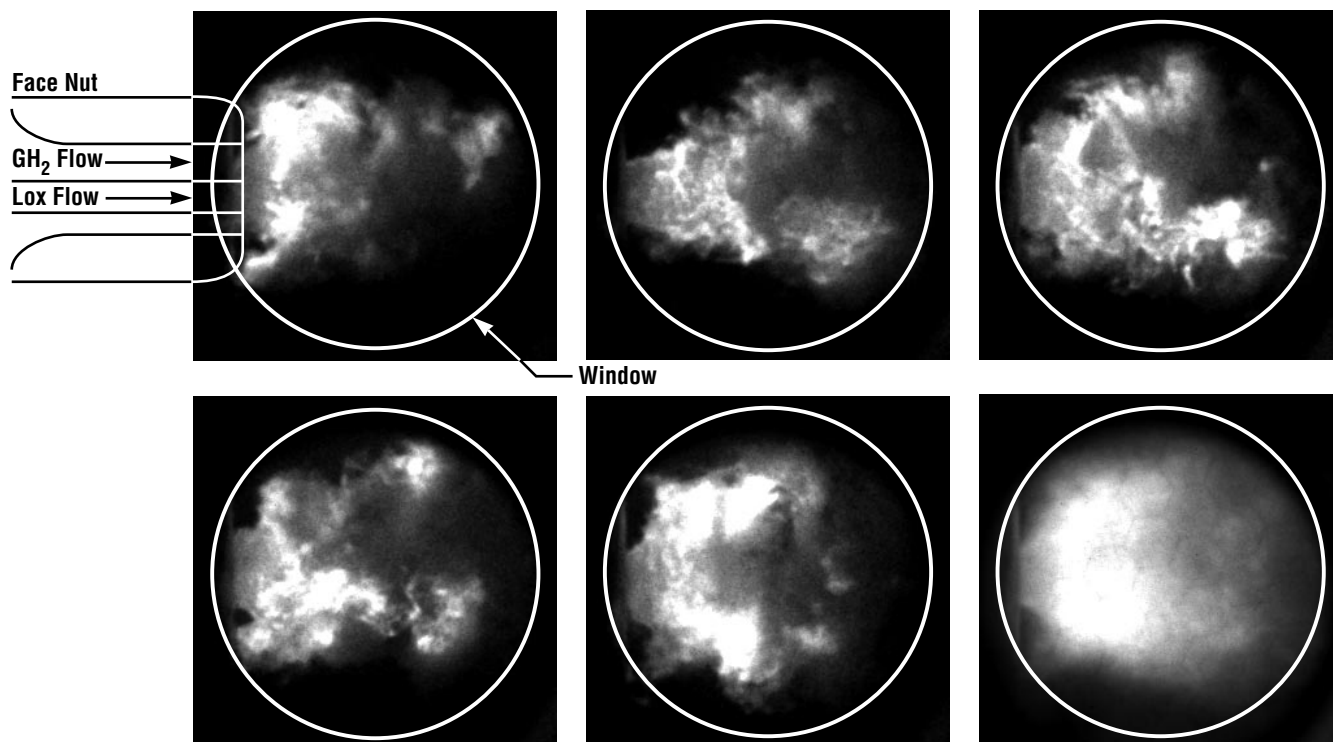


FIGURE 9.—Ultraviolet images of combustion zone at first window position ($x=0.5$ in).